Designing an underground lead and zink mine using *in-situ* initial state of stresses

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ABSTRACT: One of the most important parameters in designing the openings in underground works is the initial state of stresses, based on which the geometrical dimensions of the openings and the volume of required supports are determined. A number of tests have been conducted to evaluate *in-situ* stresses at the mean depth of 120 meters below the surface by means of Borehole Slotter. Dilatometer tests in the same galleries and boreholes were performed in order to find the required modulus for calculating the stresses, using Kirsch and Hooke Laws. The results show that the maximum principal stress is horizontal with the magnitude of about 5.2MPa while the intermediate one was in vertical direction. These results have been successfully used for controlling the design of geometrical dimensions, orientation of openings and advance periods.

1 INTRODUCTION

In a number of underground mining methods, parts of the deposit are left in place to support the roof and sidewalls. The optimum design of crown and rib pillars in sublevel stopping method is a major factor determining the economy and safety of the underground mining. Although, variety of methods has been developed to design crown and rib pillars, still there is not a unique method to give certain results. This is due to very complex behaviour of these pillars (Fig. 1).

![Figure 1. Position of crown and rib pillars in sublevel stopping method of mining](image)

A research has been carried out on the stability of crown and rib pillars in an underground Lead and Zinc mine. At the outset, the objective of this investigation was to develop a reliable method for designing appropriate dimensions of these pillars. To carry out these analyses, comprehensive information on the geometrical dimensions, material properties and field stresses were needed.

For controlling the design and analysis of pillars, a vast study programme was needed, among which stress measurement was in paramount importance. The present paper describes the measurement of *in-situ* stresses in the vicinity of the underground mining. These measurements, in conjunction with determining of the moduli of rock mass, were carried out inside the boreholes drilled for providing the cores for laboratory experiments.

First of all, geological and geotechnical aspects of the rock mass in the site will be briefly introduced. Then the stress measurement method and the procedure of the tests in this site will be discussed and at the end, the amount of the principal stresses and their direction will be presented.

2 SITE INVESTIGATION

2.1 Geology

The Lead and Zinc mine has been located in about 165km to the East of city of Yazd, central part of Iran, and from tectonic point of view in a complicated folded and faulted zone. This mine comprises an estimated final deposit of about 3.5 million tones, major part of which will be extracted in sublevel stopping method.
The main rock mass is igneous rock containing black Shale, intergrowth of Dolomite with disseminated Pyrite.

2.2 Geomechanical properties of rock mass

After geological and tectonic investigations, it was found that the major faults of the region divide the deposit into four main parts, one of which is more important from the deposit amount of view. Thus, it has been concentrated on this part in this research.

In order to determine the properties of discontinuities such as: strike, dip and dip direction, spacing, extension, consistency, opening, infilling materials, roughness and weathering conditions, the Scan Line method was used in different direction in order to have three dimensional information about the discontinuities. 25 scan lines were used in this regard and three major joint sets, including bedding plane, were recognized using DIPS software. UNWEDGE software was also used for controlling probable instability of the wedges in the underground spaces.

It should be noted that the young’s modulus and the modulus of deformation measured by means of a flexible dilatometer is maximum along and parallel to the beddings and reduces considerably across them. These results in addition with the results of stress measurement and the following rock properties have been used for controlling three dimensional comprehensive analyses of the underground mine spaces:

Rock properties:

\[ E = 13.8 - 25.6 \text{ GPa} \]
\[ \text{UCS} = 45 - 129 \text{ MPa} \]
\[ \nu = 0.2 - 0.27 \]
\[ \gamma = 26 - 28 \text{ kN/m}^3 \]

Bedding planes:

Normal stiffness\( = 34 - 45 \text{ GPa/m} \)
Shear stiffness \( = 5.2 - 6.7 \text{ GPa/m} \)
Friction angle \( = 31 - 35 \text{ degrees} \)
Cohesion \( = 0.6 - 1.2 \text{ MPa} \)

Rock mass classification:

RMR \( = 79 \)
Q \( = 9.1 \)

3 TEST PERFORMANCE


Borehole Slotter is a 2D stress measuring technique. It aims at determining in-situ rock stress by locally releasing tangential stress at a borehole surface. For a linear elastic material, these tangential stresses have a unique relationship with the in-situ state of stress in the far field of the tested borehole (Kirsch’s solution of a circular hole in a stressed plate).

The borehole slotting system is made up of six principal components:

a) Borehole probe (slotter), containing the small diamond saw for cutting a radial slot into the borehole wall for producing local stress relief. The recoverable tangential strain sensor for measuring the stress relief effects during and after slotting, and also some sensors for measuring the temperature and orientation of the probe;

b) Electrical control and read out unit, which monitors the signals of four sensors of the slotter and shows the records by LCD display and strip chart recorder;

c) Pneumatic and hydraulic control unit, which allows the activation and control of all pneumatic and hydraulic operations of the probe;

d) Pressure vessel for cooling water with a capacity of about 25 litres;

e) Cables, hoses and accessories including transportation boxes; and

f) Software. The measuring principles and full description of the borehole slotting system could be found in a paper by Bock (1986).

3.1 Preparatory works

Three test sites were prepared in three HQ approximately orthogonal boreholes (96 mm \( \phi \)) drilled at the end of an access gallery in the vicinity of the deposit. A total of 18 individual tests were completed for measuring the in-situ stress. Some dilatometer tests were performed in the same boreholes to measure the rock mass modulus of deformability which was used in calculating the in-situ stress. As mentioned before, the rock mass modulus of deformability had various amounts with the mean value of 20 GPa.
3.2 Testing method and programme

A typical test set up is shown in figure 2 which is a view looking directly down the HQ borehole. A radial slot is cut into the borehole wall with a small diamond-impregnated saw. The slot is about 1mm wide and about 25mm deep. Before, during and after slotting, tangential strain is measured at the borehole wall in the vicinity of the slot where practically full stress relief occurs.

The test started with drilling and flushing the borehole with water and air. Then the slotter probe were sent down the borehole and installed at desired depth. The slotter were oriented via interconnecting rods and clamped in the position. The motor of slotter blade which is rotated by means of compressed air were started. The tangential strain sensor was brought in contact with the surface of borehole wall and waited until output signal to be stabilized. Then the first slot was cut in a continuous motion. During the completion of the slot, the signals of the strain sensor were recorded in the read out unit. The blade was then retracted, the slotter motor was shut down and cooling water was turned off. The same procedure followed for the second and third slot which spaced 120 degrees from each other and the recorded strip charts and data was inspected after each slot. If the recorded data and charts seemed meaningful, a 2D measurement was assumed to be finished and the successive test in the same borehole was programmed to be started. After finishing anticipated tests in each borehole, the slotter probe was retrieved from the borehole and placed in the other borehole to start the next series of stress measurement. A typical test output from a single test with six slots is shown in figure 3.

Figure 2. Principles of borehole slotter

At a particular test location, three to six slotting test with cuts in independent direction were made for a single 2D measurement. The theory of linear elasticity was employed to transfer the strain readings into stresses. This means that the moduli of tested rock must be known for the stress measurement. As mentioned previously, dilatometer tests were performed after the completion of slotter tests in the boreholes in order to obtain the moduli of rock mass. IF96 type dilatometer was used for this purpose, the characteristics of which may be found in the Interfels catalogue. The procedure and method of the moduli determination by means of this equipment may also be found in the same document.

Figure 3 Typical records for a single test with six slots
CALCULATION AND PRESENTATION OF RESULTS

The conversion of strains into stresses starts with the Kirsch equation, which describes the tangential stress distribution around a circular hole in an infinite elastic plate. By applying Hooke’s law an equation can be derived, that relates the measured strains at the borehole wall to the far-field values of the primary stress field:

\[
\varepsilon_\theta = \frac{1-v^2}{E} \left\{ (\sigma_x + \sigma_y) - 2(\sigma_x - \sigma_y) \cos 2\theta + \tau_{xy} \sin 2\theta \right\}
\]

where \( \varepsilon_\theta \) is the measured strain signal in the azimuth \( \theta \). For the determination of the three unknown components \( \sigma_x, \sigma_y \) and \( \tau_{xy} \) of the 2D stress tensor, three different input values for \( \varepsilon_\theta \) and \( \theta \) are required. With the components of the 2D stress tensor in an arbitrary Cartesian coordinate system, principal stress magnitudes and orientations can be obtained by calculating the eigenvectors and eigenvalues.

For the calculation of stress magnitudes from Borehole Slotter tests, Young’s modulus \( E \) and Poisson’s ratio \( v \) have to be determined independently by in-situ and laboratory tests, respectively. \( E \) is crucial for the accurate determination of stress magnitudes from slotter tests and, furthermore, for all relief techniques, that do not supply stress magnitudes directly.

Having considered the abovementioned theory and simplifications, the 2D stresses were calculated and presented in form of tables and diagrams, an example of which is shown in figure 4. The 2D magnitude of stresses and orientation of maximum stress in a single borehole have been depicted in this figure. The three dimensional state of stress was determined by combining the 2D results from each of the boreholes. The analysis of the results shows that the maximum principal stress is nearly horizontal while the intermediate one is vertical. The magnitude of the principal stresses in the vicinity of test site have been evaluated to be about 5.2MPa, 3.1MPa and 2.75MPa and the direction of maximum principal stress is about 250 degrees. One may easily show that there is a good conformity between the magnitude of vertical intermediate stress with the vertical stress calculated from the overburden mean height and density of the rock mass.

These results have been used for controlling the design of openings geometry, the dimensions of the crown and rib pillars and orientation of openings and advance periods.

Figure 4 summary plot of stress measurements carried out in a borehole

CONCLUDING REMARKS

In sublevel stopping mining method, parts of the deposit are left in place to support the roof and sidewalls. The optimum design of crown and rib pillars which are major factors determining the economy and safety of the underground mining in this method is directly under the influence of the in-situ stresses. Rock mass strength was also required as the input data of the stability analysis and to estimate the dimensions of the loosening region accompanied with the excavation.

Laboratory and in-situ tests were performed in order to find the main input data in controlling the designed openings. Laboratory tests
were conducted for finding geomechanical properties of the host and the deposit rock masses, while *in-situ* stress measurement was performed by means of Borehole Slotter to determine the state of stresses. Laboratory data indicated that the rock masses were in good quality and fairly strong and *in-situ* measurement showed low level of principal stresses. With these results the crown and rib pillars in this mine were apparently, from the stability point of view, under very favorable condition. Therefore, their dimensions could be reduced by 15 to 20 percent. This may be very appreciable in increasing the deposit recovery and, therefore, benefitting the client.

### 6 REFERENCES


